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The Verme Weather Severity Index, harvest statistics, and white-tailed deer *(Odocoileus virginianus)* in southwestern Manitoba

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ABSTRACT

Chillometer, snow depth, and pentrometer data were collected in southwestern Manitoba for the winters of 1979-80 to 1984-85. The chillometer data were not indicative of annual or geographic variation in weather severity, and the chillometer was not a biologically valid model of thermal stress for white-tailed deer. The pentrometer poorly modeled the impact of Manitoba snow conditions on white-tailed deer. The measurement and subsequent reporting of snow depth and pentrometer in metric units violated the hypothesis necessary for calculation of a Verme Weather Severity Index. Additionally, index formation is of limited use given the availability of modern statistical methodology and computers, and would likely provide little benefit over snow depth due to lack of independence among constituent variables. Harvest statistics for white-tailed deer, as generated from hunter questionnaire data, were inaccurate. The fawn/fawn plus adult doe statistic, a potential measure of recruitment, appeared to be useful as a trend indicator. The adult male/adult statistic appeared to be unreliable as a trend indicator and is of little, if any, value to managers. For many applications of such statistics, questionnaire-generated estimates should not be used, or used with extreme caution. Harvest composition statistics, as estimated in Manitoba by the hunter questionnaire method, may substantially understate the impact of sport harvest on white-tailed deer recruitment. There were no relationships between harvest statistics and measures of winter weather severity; however, predicted trends were apparent for the fawn/fawn plus adult doe statistic, samples were small, and other factors may have influenced this result. The relationship between white-tailed deer and their winter environment in Manitoba can only be determined through research directed towards this purpose as relationships from other areas and environments will often not apply. To maximize the usefulness of data, it is suggested that new programs of data collection include an individual proficient in use of the scientific method.

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TABLE OF CONTENTS

	Page
ABSTRACT	i
ACKNOWLEDGEMENTS	ii
LIST OF TABLES	iv
INTRODUCTION	1
STUDY AREA AND METHODS	2
RESULTS	4
THE VERME INDEX	4
Chillometer	4
Snow Depth and Pentrometer	5
ACCURACY OF HARVEST STATISTICS	6
Accuracy	6
Impact on Estimation of Harvest	9
HARVEST STATISTICS AND WINTER SEVERITY	10
DISCUSSION	11
THE VERME INDEX	11
Chillometer	11
Pentrometer	14
Snow Depth	18
Impact of Metrification	18
Effect of Interrelationship of Constituent Variables on an Index	19
The Concept of an Index	20
ACCURACY OF HARVEST STATISTICS	21
HARVEST STATISTICS AND WINTER SEVERITY	24
FAILURE OF MODEL DEVELOPMENT	27
RECOMMENDATIONS	28
LITERATURE CITED	30

LIST OF TABLES

Table		Page
1.	Chillometer (kW•hour) and cumulative minimum daily temperature (C) for the years 1979-80 to 1984-85 from Brandon, Virden, and Neelin	5
2.	Cumulative pentrometer (cm•week) and snow depth (cm•week) for the years 1979-80 to 1984-85 from Brandon, Virden, and Neelin	6
3.	Bag check and questionnaire-generated harvest statistics for the years 1980 to 1983 from a combination of Game Hunting Areas 27 and 28	7
4.	Questionnaire-generated harvest statistics for residents and non-residents who hunted in Game Hunting Areas 27 and/or 28 during 1985	8
5.	Questionnaire-generated harvest statistics for all hunters (resident and non-resident) and non-resident hunters from Game Hunting Areas 27 and/or 28 during 1985. Statistics are for both seasons combined	9
6.	Impact of utilizing questionnaire as compared to bag check data on the estimated distribution of harvest between ages and sexes. Data generated with mean estimates from Table 3 and a theoretical harvest of 1000 deer	9
7.	Regression statistics for harvest statistics (bag check data) vs. weather severity measures from the previous winter for the Virden area, 1980-1983. Data from Tables 1 and 3	10
8.	Foot load (g/cm^2) for various sex and age classes of white-tailed deer. Data from Telfer and Kelsall (1979)	16
9.	The influence of non-independence of constituent variables on index formation	20

INTRODUCTION

Winter is an important and often severe test of survival for many species of animals. Food is often limited and may be of poor quality. Temperatures are low and snow may severely restrict the ability of animals to forage. This test of fitness represents a strong selective force in defining the genetics and age structure of animal populations. Individual species have adapted to winter conditions in many fashions. Morphological modifications include a relatively thick winter pelage, long legs, and relatively large, supportive feet. Some animals will burrow into snow to take advantage of its insulative ability while others have adapted behaviorally through migration.

The biology and success of white-tailed deer (Odocoileus virginianus) in Manitoba is related to the winter conditions to which they are subjected. The influence of winter is dramatic and obvious when large numbers of white-tailed deer die in a malnourished condition. The effect of winter on deer populations is often less obvious. Severe winters may affect the survival of fawns born during the spring thereby affecting population characteristics several years into the future. Antler development of male white-tailed deer may be restricted as a consequence of a severe winter. The relative severity of winter may also determine the nature of the relationship between white-tailed deer and predators like coyotes (Canis latrans) and wolves (Canis lupus).

Knowledge relative to the effect of winter on white-tailed deer populations is important for several reasons. If the relationships between winter severity and mortality or productivity are known, sound decisions may be made regarding the implementation of deer feeding programs. Such relationships could be used to forecast fall deer populations in terms of number and age/sex structure. This knowledge would assist managers to make sound decisions relative to sport harvest seasons.

In Manitoba, various measures have been collected in attempting to assess the impact of winter weather on white-tailed deer (Soprovich and Hristienko 1989). Measures necessary to calculation of the winter weather severity index developed by Verme (1968) were collected in southwestern Manitoba for the winters of 1979-80 to 1984-85. Verme's weather severity index (hereafter referred to as the Verme WSI) included snow depth, a

measure of snow compaction, and a measure of thermal stress to model the influence of winter weather on white-tailed deer in Michigan. Subsequently, Verme (1977) found the proportion of does in good physical condition and predicted natal birth weight to relate to the Verme WSI. As fetal birth weight and mortality are strongly related (Verme 1962, 1963), this suggests that natal mortality and subsequent recruitment would relate to the Verme WSI. Similarly, Karns (1980) found an index of overwinter mortality to relate to the Verme WSI for white-tailed deer in Minnesota.

The primary purpose of this study was to assess the usefulness of the data collected from Manitoba for modeling the impact of winter weather on white-tailed deer survival and recruitment. To complete this task, it was necessary to assess the quality of the data collected to calculate the Verme WSI and the quality of the harvest data.

STUDY AREA AND METHODS

Data necessary to calculation of the Verme WSI were collected from sites near Brandon, Neelin, and Virden in southwestern Manitoba. Snow-related measures were collected from permanent transects at each site. Each transect had 10 permanent stations with each station located 1 chain (20 m) from adjacent stations (Milliken 1978). At each station, snow depth and pentrometer (compaction gauge) depth were measured in cm each week, and a mean value calculated for each of these variables. Snow depth was measured from a meter stick fastened to the stake marking each permanent station. The pentrometer was a 90 cm copper pipe weighing 1.36 kg (3 lbs) with a basal surface area of 6.45 cm^2 (1 $inch^2$). The pentrometer was lowered until its base touched the surface of the snow, released (Milliken 1981), and the depth to which it sunk was the pentrometer measure. Verme (1968) believed this depth to reasonably simulate the sinking depth of white-tailed deer under snow conditions other than weak surface crust.

Thermal stress was modeled by an instrument called a chillometer (Verme 1968). The chillometer consisted of a pressure cooker equipped with a 750 W heating element and a thermoregulator. Each chillometer was filled with 4.55 kg (10 lbs) of distilled water. Chillometers were placed on 1.22 m X 1.22 m (4 ft by 4 ft) stands approximately 1.22 m (4 ft) off the ground with the box of the element and the dial of the thermoregulator

facing south. Stands were placed at least 13.72 m (15 yards) from buildings or trees. Chillometers were connected to an electrical outlet through a 115 V 60 ampere electricity meter. Thermoswitches were adjusted to maintain the water temperature at 4 C. The chillometer measure was the amount of energy, measured in kW•hours, required to maintain the water at 4 C (Milliken 1981) for each week. The chillometer apparatus used in Manitoba differed from that detailed by Verme (1968) with respect to distance from buildings and height above the ground.

Data were to be collected every Monday from 1 November (or when the first snow had fallen) to 30 April (or when all the snow had disappeared). The addition of weekly chillometer data for this period resulted in a chillometer value for each winter. Similarly, summation of weekly snow depth and pentrometer resulted in annual values. Addition of the 3 values resulted in a Manitoba WSI which differed from Verme's model in that snow depth and pentrometer were measured in metric units. Chillometer values from each station were compared to cumulative minimum daily temperature values calculated with data from nearby meteorological stations (reported in the Monthly Record Series, Atmospheric Environment Service, Environment Canada). Minimum daily temperatures were summed to result in a cumulative minimum daily temperature from each meteorological station for each winter. The division of this value by the number of days between 1 November and 30 April would result in a mean minimum daily temperature for this period. Chillometer data for the Brandon, Virden, and Neelin weather severity stations were compared to temperature data for the Brandon, Virden, and Ninette IW meteorological stations respectively. Weather severity data analyzed in this study were obtained from annual reports by Milliken (1981) and Chranowski (1982, 1983, 1984, 1985).

Harvest statistics originated from 2 sources. Data were available from an annual bag check conducted in the Virden area where the sample of deer originated primarily from Game Hunting Areas 27 and 28 (B. Pelechaty, Man. Dept. Nat. Resour., pers. commun.). These harvest statistics were compared to those generated by the annual hunter questionnaire for Game Hunting Areas 27 and 28 combined (Vanderpont 1981, 1982, 1983, 1984).

Bag check data were available for deer hunting seasons from 1973 to 1985 (Goulden 1984, H. D. Goulden, Man. Dept. Nat. Resour., unpubl. data). Prior to 1979, questionnaire-generated statistics did not include the age

or sex composition of the harvest while the 1979 white-tailed deer season was bucks-only. Questionnaire-generated statistics from 1984 originated from a season structure where the first season was bucks-only and the second season any-deer. For 1985, questionnaire-generated statistics originated from a season structure where both weeks were any-deer (i.e., comparable to the 1980 to 1983 seasons); however, adult females comprised a greater proportion ($z = 4.01$, $P < 0.002$) of the harvest from the second season of unit B (analysis of data from Hummelt 1986). Consequently, bag check and questionnaire statistics were not compared for 1984 and 1985 due to a differential sampling intensity between seasons in the bag check data (B. Pelechaty, Man. Dept. Nat. Resour., pers. commun.). The only years for which data could be reasonably compared were 1980 to 1983.

The majority of the bag check data originated from roadside check stations where hunters were generally resident outside the Game Hunting Areas (B. Pelechaty, Man. Dept. Nat. Resour., pers. commun.). A bias would exist if resident hunters were sampled at a different rate from non-resident hunters and the composition of the harvest differed between groups. Questionnaires from the 1985 hunting season were sorted into 2 groups to assess the existence and extent of such a bias for Game Hunting Areas 27 and 28. One group, considered to represent resident hunters, contained questionnaires mailed from within or directly adjacent to the boundaries of the 2 Game Hunting Areas. The second group contained the remaining questionnaires and was considered to represent non-resident hunters.

RESULTS

THE VERME INDEX

Chillometer

At Brandon (Table 1), the chillometer value recorded for the warmest winter (cumulative minimum daily temperature of -2103) was higher (183) than that recorded for the second coldest winter (176). Similarly, a difference of 47 kW·hours (26.7%) was recorded from the 2 coldest winters which were almost identical in terms of temperature. Higher chillometer values were recorded for relatively warm winters at the other weather severity monitoring stations (eg., 1979-80 compared to 1984-85 at Virden, 1979-80 compared to 1981-82 at Neelin).

Cumulative minimum daily temperature and chillometer values were consistently higher at Brandon than the other stations; however, the differences in chillometer values were substantially greater than those for cumulative minimum daily temperature (Table 1). For example, cumulative minimum daily temperature was almost identical for Brandon (-2697), Virden (-2653), and Neelin (-2658) for the winter of 1981-82 yet the chillometer values for Virden and Neelin were only 63.5% and 51.4% that of Brandon.

It was not possible to detect a linear relationship between the chillometer value (dependent) and cumulative minimum daily temperature (independent) for Brandon ($F = 3.45$, $df = 1,4$, $P \approx 0.15$), Virden ($F = 1.17$, $df = 1,4$, $P > 0.25$), or Neelin ($F = 0.85$, $df = 1,4$, $P > 0.25$). The fit of the data to a linear model was poor for both Virden ($r^2 = 0.23$) and Neelin ($r^2 = 0.18$) but relatively good for Brandon ($r^2 = 0.46$).

Table 1. Chillometer (kW·hour) and cumulative minimum daily temperature (C) for the years 1979-80 to 1984-85 from Brandon, Virden, and Neelin.

	Weather severity station					
	Brandon		Virden		Neelin	
Year	Chillometer	Temp*	Chillometer	Temp*	Chillometer	Temp*
1979-80	223	-2767	156	-2516	149	-2407
1980-81	183	-2103	116	-1933	110	-1893
1981-82	222	-2697	141	-2653	114	-2658
1982-83	139	-2248	113	-2095	94	-1903
1983-84	148	-2231	125	-2067	96	-2114
1984-85	176	-2757	110	-2598	103	-2490

*Temp represents cumulative minimum daily temperature.

Snow Depth and Pentrometer

The relative value of the annual pentrometer measurement to the annual snow depth measurement (pentrometer ÷ snow depth X 100) varied little between stations (Table 2). Additionally, this value was generally consistent between years with the exception of 1982-83 when the value was

42% for Brandon, 44% for Virden, and 30% for Neelin. A strong linear relationship between pentrometer and snow depth existed for Brandon ($F = 25.98$, $df = 1,4$, $P < 0.01$, $r^2 = 0.87$), Virden ($F = 28.72$, $df = 1,4$, $P < 0.01$, $r^2 = 0.88$), and Neelin ($F = 75.23$, $df = 1,4$, $P < 0.001$, $r^2 = 0.95$).

Table 2. Cumulative pentrometer (cm·week) and snow depth (cm·week) for the years 1979-80 to 1984-85 from Brandon, Virden, and Neelin.

Weather severity station	Year	Pentrometer	Snow depth	$\frac{\text{Pentrometer}}{\text{Snow depth}} \times 100$ (%)
Brandon	1979-80	500	512	98
	1980-81	162	194	84
	1981-82	298	368	81
	1982-83	130	308	42
	1983-84	247	299	83
	1984-85	595	799	74
Virden	1979-80	422	426	99
	1980-81	96	108	89
	1981-82	242	266	91
	1982-83	115	261	44
	1983-84	188	204	92
	1984-85	453	508	89
Neelin	1979-80	421	439	96
	1980-81	135	138	98
	1981-82	314	366	86
	1982-83	41	136	30
	1983-84	268	284	94
	1984-85	382	391	98

ACCURACY OF HARVEST STATISTICS

Accuracy

The proportion of males in the adult harvest (Table 3) was less in the bag check data for 1981 ($X^2 = 4.63$, $df = 1$, $P < 0.05$) and 1983 ($X^2 = 11.05$, $df = 1$, $P < 0.005$). For 1983, the proportion of males in the adult harvest was estimated at 63.5% by the questionnaire method and 48.1% by the bag check method. No difference in the statistics could be detected for 1980 ($X^2 = 0.73$, $df = 1$, $P \approx 0.40$) or 1982 ($X^2 = 2.29$, $df = 1$, $P \approx 0.14$).

The proportion of fawns in the combined fawn and adult female

harvest was greater in the bag check data of 1980 ($X^2 = 5.07$, df = 1, $P < 0.025$), 1981 ($X^2 = 6.86$, df = 1, $P < 0.01$), and 1983 ($X^2 = 5.57$, df = 1, $P < 0.025$) but not different at standard levels for 1982 ($X^2 = 2.67$, df = 1, $P \approx 0.10$). The sex of the fawns was not indicated in the bag check data. For the questionnaire data, the proportion of males in the fawn harvest varied between 0.645 and 0.745, proportions equivalent to 1.82 and 2.92 males per female respectively.

Table 3. Bag check and questionnaire-generated harvest statistics for the years 1980 to 1983 from a combination of Game Hunting Areas 27 and 28.

	Harvest statistic					
	Number of male adults / Number of adults (n)		Number of fawns / Number of fawns and adult females (n)		Number of male fawns / Number of fawns (n)	
Year	Questionnaire	Bag check	Questionnaire	Bag check	Questionnaire	Bag check
1980	0.633(485)	0.666(305)	0.355(276)[b]	0.463(190)[b]	0.735(98)	-
1981	0.658(441)[a]	0.565(200)[a]	0.381(244)[c]	0.515(179)[c]	0.645(93)	-
1982	0.596(401)	0.533(259)	0.367(256)	0.445(218)	0.745(94)	-
1983	0.635(342)[d]	0.481(189)[d]	0.396(207)[b]	0.517(203)[b]	0.646(82)	-
Mean	0.631	0.561	0.375	0.485	0.693	-

[a] $P < 0.05$, [b] $P < 0.025$, [c] $P < 0.01$, [d] $P < 0.005$; X^2 test with Yates correction for continuity.

For the proportion of males in the adult harvest, there was no linear relationship between sources of data ($F = 0.05$, df = 1,2, $P > 0.25$) and the fit of the data was extremely weak ($r^2 = 0.03$). Similarly, it was not possible to detect a linear relationship between data sources (bag check estimate as the independent variable) for the proportion of fawns in the combined fawn and adult female harvest ($F = 4.43$, df = 1,2, $0.10 < P < 0.25$). Unlike the previous statistic, the fit to the linear model ($r^2 = 0.69$) was good for this statistic. Additionally, the positive slope of the

line indicated that an increase in the proportion of fawns (to fawns and adult females) in the bag check data would be accompanied by an increase in this proportion in the questionnaire data.

For the 1985 season (data from Hummelt 1986), the proportion of males in the adult harvest of unit B was greater for the first than the second season ($z = 3.52$, $P < 0.002$). Although the trend was similar for hunters from Game Hunting Areas 27 and 28 (Table 4), the proportion was not significantly different for residents ($X^2 = 0.13$, $df = 1$, $P \approx 0.70$; Yates correction for continuity) or non-residents ($X^2 = 0.45$, $df = 1$, $P \approx 0.50$; Yates correction for continuity). Similarly, the proportion of males in the adult harvest did not differ between groups for season 1 ($X^2 = 0.46$, $df = 1$, $P \approx 0.50$; Yates correction for continuity) or season 2 ($X^2 = 0.46$, $df = 1$, $P \approx 0.50$; Yates correction for continuity). With data from both seasons combined, the proportion of males in the adult harvest was not different (one-tailed test, $z = 0.98$, $P = 0.16$) between hunter groups.

Table 4. Questionnaire-generated harvest statistics for residents and non-residents who hunted in Game Hunting Areas 27 and/or 28 during 1985.

Statistic	Season[a]	Resident hunters (n)	Non-resident hunters (n)
Number of male adults	1	0.69(39)	0.62(133)
Number of adults	2	0.63(52)	0.55(51)
	Both	0.66(91)	0.60(184)
Number of fawns	1	0.29(17)	0.35(78)
Number of fawns and	2	0.21(24)	0.28(32)
adult females	Both	0.24(41)	0.33(110)

[a]1 refers to date choice 1, 2 refers to date choice 2.

The proportion of fawns in the combined fawn and adult female harvest did not differ between groups for season 1 ($X^2 = 0.01$, $df = 1$, $P > 0.90$; Yates correction for continuity) or season 2 ($X^2 = 0.16$, $df = 1$, $P > 0.60$; Yates correction for continuity). Similarly, this proportion was not different between seasons for resident hunters ($X^2 = 0.07$, $df = 1$, $P \approx 0.80$;

Yates correction for continuity) or non-resident hunters ($X^2 = 0.20$, df = 1, $P > 0.60$; Yates correction for continuity). With data from both seasons combined, the proportion of fawns in the fawn and adult female harvest did not differ by residence ($X^2 = 0.63$, df = 1, $P > 0.40$; Yates correction for continuity).

Inclusion of questionnaires from resident hunters, with those from non-residents (non-residents assumed to be representative of the bag check data), did not substantially alter estimates based on data from non-residents alone (Table 5).

Table 5. Questionnaire-generated harvest statistics for all hunters (resident and non-resident) and non-resident hunters from Game Hunting Areas 27 and/or 28 during 1985. Statistics are for both seasons combined.

Statistic	All hunters[a]	Non-resident hunters[b]
$\frac{\text{Number of adult males}}{\text{Number of adults}}$	0.618	0.598
$\frac{\text{Number of fawns}}{\text{Number of fawns and adult females}}$	0.305	0.327

[a]Equivalent to questionnaire data from previous years.
[b]Representative of bag check data from previous years.

Impact on Estimation of Harvest

Table 6. Impact of utilizing questionnaire as compared to bag check data on the estimated distribution of harvest between ages and sexes. Data generated with mean estimates from Table 3 and a theoretical harvest of 1000 deer.

Source of data	Number of adult males	Number of adult females	Number of fawns	Total harvest
Questionnaire	5,166	3,021	1,813	10,000
Bag check	3,968	3,106	2,926	10,000

If bag check data were accurate, the questionnaire method resulted in extremely inaccurate estimates for the contribution of adult males and fawns to the harvest (Table 6).

HARVEST STATISTICS AND WINTER SEVERITY

There were no significant linear relationships (Table 7) between the 2 harvest statistics (bag check data, dependent variables) and the environmental measures from the previous winter (independent variables). The slopes of the regression lines between the proportion of males in the adult harvest and the measures of winter severity were positive. The best fit of the data for the proportion of fawns in the fawn and adult female harvest was with the chillometer ($r^2 = 0.77$, $P \approx 0.15$). The trend was for this proportion to decrease with increasing severity (negative slope) for each of the environmental measures.

Harvest statistics collected in a consistent manner for similar seasons (any age or sex, length, dates) were available for questionnaire data from 1980-1983 and 1985. With this source of data, a linear relationship between number of fawns/number of fawns and adult does and

Table 7. Regression statistics for harvest statistics (bag check data) vs. weather severity measures from the previous winter for the Virden area, 1980-1983. Data from Tables 1 and 3.

Weather severity measure	Harvest statistic: Number of adult males/ number of adults			Harvest statistic: Number of fawns/ number of fawns and adult females		
	r^2	F	P[a]	r^2	F	P[a]
Pentrometer	0.66	3.85	≈0.20	0.57	2.62	≈0.25
Snow depth	0.30	0.85	>0.25	0.35	1.08	>0.25
Chillometer	0.60	2.97	>0.20	0.77	6.52	≈0.15
WSI[b]	0.51	2.09	>0.25	0.51	2.06	>0.25

[a]df were 1,2.
[b]WSI was the summation of pentrometer, snow depth, and chillometer measurements using the Manitoba model (snow depth and pentrometer in metric measurements).

chillometer was apparent for data from 1980-1983 (r^2 = 0.92, F = 21.88, df = 1,2, P < 0.05) but non-existent when the datum from 1985 was included in the regression (r^2 = 0.01, F = 0.01, df = 1,3, P > 0.25). For the complete data set, the number of adult males/number of adults (r^2 = 0.15, F = 0.54, df = 1,3, P > 0.25) and number of fawns/number of fawns and adult does (r^2 = 0.18, F = 0.64, df = 1,3, P > 0.25) were not related to the Verme Weather Severity Index (snow depth and pentrometer converted to Imperial equivalents).

DISCUSSION

THE VERME INDEX

Chillometer

Verme (1968) investigated the impact of ambient temperature, wind, solar radiation, snowfall, and relative humidity on the chillometer. This instrument was influenced primarily by ambient temperature (r^2 = 0.78 for the 2 variables) while wind, although statistically significant, was functionally unimportant due to its small coefficient within the regression equation. Verme (1968) stated that chillometers were located in "a small clearing completely exposed to prevailing winds." Such a clearing is not defined; however, the picture of a monitoring site (Fig. 2 in Verme 1968) illustrates that substantial wooded cover was located near the chillometer. As wind velocity and profile are related to the life-form, height, and density of vegetation (Moen 1973), the minimal influence of wind on the chillometer likely resulted from the protection afforded by adjacent wooded cover.

Contrary to Verme (1968), the relationship between ambient temperature and the chillometer could not be detected with data from Brandon, Virden, or Neelin. Although the sample was small, the fit of the data to the linear model was very poor for Virden and Neelin. For Brandon, the analysis suggested the possibility of a statistically significant result with a larger sample; however, the fit was still poor relative to Verme (1968). For weather severity monitoring stations located at other sites in Manitoba, Soprovich and Hristienko (1989) found excellent to non-existent linear relationships between the chillometer and ambient temperature.

There are a number of potential explanations for the unexpected lack of a relationship between the chillometer and ambient temperature. Observed results may have been influenced by some instances of missing data or by the annual and geographic (station) variation in the initiation and termination of data collection. For example, collection of chillometer data was initiated at Virden on 17 December, 1979 and 3 November, 1980 (Milliken 1981). Any difference in calibration of the chillometer between years and stations could have adversely influenced the measure and analysis. As minimum daily temperature was accumulated for the period 1 November to 30 April inclusive, selection of a slightly different period might have yielded somewhat different results. The temperature data used in the analysis came from meteorological stations located varying distances from the weather severity stations. Although temperatures may not have been directly representative of weather severity stations, relative changes between years would very likely be similar (D. W. Soprovich, Man. Dept. Nat. Resour., unpubl. data). A small sample, particularly for Brandon, may have been responsible for the inability to detect a relationship.

The monitoring sites exhibited considerable variation relative to exposure to wind and it is likely that wind impacted each chillometer to a variable and unknown degree. For example, the chillometer at the Brandon weather severity station was located at an extremely exposed site while that for Neelin was well-sheltered by adjacent wooded cover (D. J. Chranowski, Man. Dept. Nat. Resour., pers. commun.). This difference in microclimate was likely most responsible for the relatively high chillometer values recorded at the Brandon weather severity station. It appears that chillometer values, due to a lack of standardization in microsite selection, are representative of the specific microclimate located at each site and are therefore not directly comparable to values recorded at other sites. A consequence of this problem is that the ability to compare the relative severity of winters geographically is negated and the measure is poorly representative of the environment which a local white-tailed deer population must contend with.

The primary purpose for collecting chillometer data was to allow comparison of the weather severity between years. The lack of a relationship between the chillometer and ambient temperature is important because it indicates that factors other than temperature have influenced

the chillometer, and that the chillometer was not particularly useful as a measure of annual variation in the weather severity for any station.

The chillometer was designed to measure the influence of thermal stress on white-tailed deer from northern Michigan (Verme 1968). In that environment, the influence of wind on the chillometer was virtually non-existent and likely reflected a biologically meaningful measure, relative to wind, for this area with considerable wooded cover.

Wind can substantially decrease the insulative capabilities of hair thereby leading to increased energy requirements (Parker and Robbins 1984). Ungulates can utilize cover to minimize the effect of wind (Moen 1968) and appear to select sites and posture for thermal benefit (Gates and Hudson 1981, Parker and Robbins 1984). In southwestern Manitoba, wind could influence white-tailed deer in two primary ways. Wind has the potential to directly increase the energetic cost of homeostasis; however, an increased cost which results when a deer stands in the open could become negligible or non-existent if the deer chose to utilize available cover. There can be no doubt that white-tailed deer in southwestern Manitoba will utilize available cover to mitigate or minimize the influence of wind. Although the magnitude of the influence of wind is unknown, it is clear that it was measured poorly by at least one chillometer (i.e., Brandon) due to poor site selection.

If the quality of available food is high, deer can maintain a positive energy balance while spending a great amount of energy on homeostasis (Moen 1968). In southwestern Manitoba, the quality of food resources is probably high when white-tailed deer forage in open environments and an observed response (survival, condition, etc.) to weather severity, as measured by a chillometer, might not occur under these circumstances. Wind might have an indirect effect upon energy balance (and survival, condition, etc.) if winds of sufficient strength and duration caused deer to utilize shelter for extended periods of time thereby influencing the quality and/or quantity of food eaten.

Although solar radiation, snowfall, and relative humidity did not exert a measurable effect on the chillometer, Verme (1968) suggested that the potential influence of solar radiation and snowfall was substantially decreased due to the presence of a roof above the chillometer. As solar radiation can influence the energetic cost of homeostasis substantially

(Parker and Robbins 1984), the inability to incorporate solar radiation effects constitutes a significant fault of the chillometer in modeling the impact of environment on white-tailed deer. In summary, it appears that the chillometer, as utilized in Manitoba, has not provided a biologically valid or useful measure of the thermal stress experienced by white-tailed deer in southwestern Manitoba.

Pentrometer

Verme (1968) indicated that, with the exception of conditions of weak surface crust, the pentrometer closely simulated sinking depths of white-tailed deer in the snow conditions found in Michigan hardwoods forest. In attempting to model the influence of snow on white-tailed deer, the inference was that snow depth does not impact ability to move as severely when support is available, and that the support offered by snow could make additional food resources available to white-tailed deer. In Manitoba, the pentrometer is rarely supported by the snow depths and densities found in wooded cover (raw data from this study, Soprovich and Hristienko 1989). The pentrometer usually sinks to ground level until a surface crust develops, generally during the later part of the winter. The pentrometer may also be impeded by crust layers (and possibly dense layers) within the snow column.

The different performance of the pentrometer in Manitoba is evidenced by the fact that cumulative pentrometer and cumulative snow depth were similar for most years, the exception being the winter of 1982-83 when cumulative pentrometer comprised 42%, 44%, and 30% of cumulative snow depth for Brandon, Virden, and Neelin respectively. The pentrometer was unable to penetrate the surface of the snow during the early and later parts of this winter due to crust which resulted from ice storms in early December and early March (Chranowski 1983).

The general lack of support of the pentrometer prior to crust formation likely results from the considerably different snow conditions found in Manitoba. Snowfall in parts of southern Manitoba average approximately 114-140 cm annually (45-55 inches annually) while snowfall over much of the Upper Michigan Peninsula amounts to more than 254 cm or 100 inches annually (Ransom 1964). There is a great deal more snow available to be compacted and to support deer in northern Michigan.

Ambient temperature is considerably higher in the Upper Peninsula as compared to Manitoba (Ransom 1964) and periodic thaws during midwinter result in lowered snow depths and strong crusts (Verme and Ozoga 1971). It is likely that this difference in temperature contributes strongly to a different performance of the pentrometer in Manitoba.

Verme (1968) found the pentrometer to be supported on the surface of the snow when deer were observed to break through a weak surface crust. This problem was controlled somewhat by conducting measurements at mid-day when solar radiation had weakened the crust. In Manitoba, the methodology for use of a pentrometer required collection of the measurement in the morning. During March 1983 in southwestern Manitoba, Chranowski (Man. Dept. Nat. Resour., pers. commun.) observed deer to frequently break through a strong crust which supported the pentrometer. It is probable that many pentrometer measurements collected under conditions of surface crust in Manitoba indicate that white-tailed deer are being supported when in reality, deer are breaking through the crust.

The foot load of white-tailed deer is considerably greater than the 211 g/cm^2 (3 lbs/inch^2) of surface pressure exerted by a pentrometer (Table 8) which suggests that deer exert considerably more pressure on the surface of the snow than does a pentrometer. Although these foot loads are for white-tailed deer from Elk Island National Park, Alberta (Telfer and Kelsall 1979), they should be representative of white-tailed deer from southwestern Manitoba because they are believed to be the same subspecies (Baker 1984). Similarly, Kucera (1976) estimated foot load at 200-400 g/cm^2 for walking and 500 g/cm^2 for running yearling and adult white-tailed deer from the Delta Marsh, Manitoba.

Foot load varies by age and sex for white-tailed deer (Table 8). In particular, fawns have a substantially lower foot load than do older deer, which could be an advantage under conditions of dense snow or hard crust (Telfer and Kelsall 1979). Foot loads of older deer are much greater than the surface pressure exerted by a pentrometer. This suggests that the pentrometer would poorly model support for these older deer under Manitoba conditions of surface crust and explains the observations by Chranowski (Man. Dept. Nat. Resour., pers. commun.) of deer breaking through a crust. The pentrometer might be useful for estimation of annual mortality if it simulates the support available to fawns because fawns represent the

Table 8. Foot load (g/cm^2) for various sex and age classes of white-tailed deer Data from Telfer and Kelsall (1979).

Sex	Age	Number in sample	Range	Mean
Male	0.5	6	239.7-360.8	287.8
	1.5	10	358.0-511.8	412.5
	2.5	5	490.7-575.8	536.1
	3.5	7	466.5-591.0	519.5
	4.5	11	439.9-602.1	512.0
Female	0.5	14	255.6-374.8[a]	327.5
	1.5	13	263.1-500.3	427.7
	2.5	11	374.9-567.8	467.1
	3.5	6	396.3-556.0	474.3
	4.5	10	374.1-564.7	474.3

[a]Upper range was 274.8 in paper but was obviously in error. Correct upper range was 374.8 (E. S. Telfer, Can. Wildl. Serv., pers. commun.).

majority of the deer which die over the winter. For estimation of the impact of snow on adult does and consequent postnatal mortality of fawns, it is likely that the pentrometer would perform poorly because foot loads of adult does are relatively great.

Telfer and Kelsall (1979) estimated foot load on the basis of pressure exerted when all 4 feet were on a surface. Additionally, their definition of foot area or supportive area may be somewhat liberal. The possible inflated estimation of supportive area, the fact that white-tailed deer generally have fewer than 4 feet on the surface during movement, and the additional force resulting from a foot descending into contact with a surface all suggest that deer generate a substantially higher surface pressure than indicated in Table 8. These factors are offset somewhat by the fact that foot load is directly related to body weight. Telfer and Kelsall (1979) examined white-tailed deer collected between 1 and 17 December, at which time body weight would likely have been near maximum. Although foot load, as estimated by Kucera (1976), generally agrees with Telfer and Kelsall (1979) for older deer, observations were likely collected during February and/or March (E. Kucera, Man. Hazardous Waste Corp., pers. commun.) when body weight would have likely been

substantially less than that of deer examined by Telfer and Kelsall (1979). Additionally, Kucera (1976) estimated food load by pushing a hardness gauge to sinking depth as opposed to determining the crust hardness necessary for support. As fawn body weight can decrease considerably and foot area may increase marginally by the time crust conditions are encountered in Manitoba, foot load could be much lower than indicated (Table 8) during the later part of some winters. All factors considered, it is likely that a white-tailed deer fawn exerts considerably greater surface pressure in late winter than does a pentrometer. To determine the accuracy of the pentrometer as a measure of support to fawns, field testing under Manitoba crust conditions is required.

Locomotion requires more energy when ungulates break through a surface crust, as compared to movement through uncrusted snow of the same depth (Fancy and White 1985). Under conditions of crust in Manitoba, a pentrometer may indicate total support and contribute nothing to a severity index when substantial additional inputs of energy are required by a deer. Similarly, at the same snow depth with no crust, a pentrometer would sink to ground level thereby contributing significantly to a severity index and erroneously indicating a more stressful snow cover. Coyote and wolf foot loads (mean foot loads of 140 and 150 g/cm^2 respectively), as calculated from data in Telfer and Kelsall (1979), are substantially less than those of white-tailed deer. In Manitoba, it is almost certain that white-tailed deer sometimes break through a crust which supports a pentrometer and either or both of these predators. Under these conditions, a pentrometer would indicate support and not contribute to a weather severity index despite the likelihood that a deer would be more vulnerable to predation. The pentrometer values which would result from the above circumstances are opposite to those which are biologically correct and would poorly model the impact of crust on white-tailed deer survival and reproduction.

Additional problems with use of a pentrometer include the possibility of non-standardization in collection of the measure, as documented elsewhere in Manitoba (Soprovich and Hristienko 1989). The pentrometer was developed for use in hardwoods forest where deer utilize forbs, grasses, and browse throughout the winter. In southwestern Manitoba, the majority of white-tailed deer frequently utilize agricultural products and residues found near wooded cover, create trails to access

these food resources (D. J. Chranowski, Man. Dept. Nat. Resour., pers. commun.), and are not required to forage as extensively in wooded cover. Consequently, these deer may often have lessened energy requirements for locomotion, although snow of sufficient depth to exclude agricultural residues might force them to forage in wooded cover. A final problem is that the pentrometer does not model the negative impacts of crust formation on food availability for white-tailed deer. While crusts may allow deer to move about more easily, they may also exclude food of high quality (eg., Hobbs 1989 for mule deer, Odocoileus hemionus), a factor likely of far greater importance, at times, than the ability to move about freely consuming food of poor quality.

Although a number of difficulties have been identified with use of a pentrometer to model weather severity for white-tailed deer, measurement of support, or characteristics of the snow profile other than depth, are valid concepts. For example, Pruitt (1981) was able to relate the distribution of caribou (Rangifer tarandus) to a model which incorporated hardness (Varrio Snow Index). Unfortunately, the pentrometer does not adequately model crust effects under Manitoba snow conditions, and its utility as a measure of snow profile effects is completely unknown.

Snow Depth

It was apparent that few problems existed with collection of snow depth data. Several weekly observations from several stations were missing; however, this problem was minor because data could generally be estimated with reasonable accuracy by interpolation. Small differences likely occurred in the collection of readings, as documented for other weather severity stations (Soprovich and Hristienko 1989); however, this problem would be minor.

Impact of Metrification

The Verme WSI is a model with the hypothesis that addition of snow depth and pentrometer measurements, in imperial units, to chillometer measurements, results in a value indicative of environmental stress to white-tailed deer. In northern Michigan, contribution of the chillometer component to total WSI was greater than the combined contribution of snow depth and pentrometer (Verme 1968). The relative importance of the

chillometer was appropriate because Verme (1968) believed that thermal stress was more important than curtailed mobility. This belief leads to a corollary to the hypothesis, this corollary being that thermal stress is most critical to white-tailed deer and should be reflected appropriately within the WSI.

In Manitoba, kW•hours were used as units of measurement for the chillometer, as indicated by Verme (1968). Although Verme (1968) constructed his WSI with an imperial unit (foot) for both snow depth and pentrometer, a metric measurement (cm) was used in Manitoba, and WSI values were reported without conversion to the imperial unit (eg., Milliken 1981). Incorporating snow depth and pentrometer in metric equivalents has substantially reduced the importance of the chillometer component to the Index. For example, the chillometer component comprised between 10.3% and 36.3% of the Weather Severity Index at Virden for the 6 years examined, a contribution considerably less than required for application of the Verme model. As winters in Manitoba are much colder and snowfall much less than in northern Michigan (Ransom 1964), the chillometer should contribute even more to the Verme Index. Use of metric equivalents in Manitoba has led to expansion of the contribution of the snow depth and pentrometer components by a factor of 30.48 (2.54 cm/inch x 12 inches/foot) and has distorted the hypothesis and corollary of Verme's model such that it is not a Verme WSI. The consequence of this violation is that biological relationships between white-tailed deer and the Verme Weather Severity Index, as reported from other areas, are irrelevant to the measure of weather severity in Manitoba. The numbers generated by the Manitoba Weather Severity Index (i.e., the WSI model used in Manitoba) are meaningless until supported by biological relationships.

Effect of Interrelationship of Constituent Variables on an Index

In Manitoba, a strong linear relationship exists for pentrometer and snow depth (this study, Soprovich and Hristienko 1989), while temperature and snow depth are related to a lesser degree (Soprovich and Hristienko 1989). As temperature and the chillometer are strongly related in the Verme model, the chillometer should be related to snow depth in Manitoba. The following theoretical example (Table 9) illustrates the ramification of such relationships on the Manitoba Weather Severity Index.

Table 9. The influence of non-independence of constituent variables on index formation.

Theoretical Manitoba relationships	Pentrometer = snow depth X 0.50 Chillometer = snow depth X 0.25
Theoretical cumulative snow depth	Year A - 100 Year B - 200
WSI using theoretical Manitoba relationships	Year A - WSI = 100 (snow depth) + 50 (pentrometer) + 25 (chillometer) = 175
	Year B - WSI = 200 (snow depth) + 100 (pentrometer) + 50 (chillometer) = 350

Snow depth and the Manitoba Weather Severity Index for year B were each twice as large as for year A, a result of the linear relationships between the constituent variables. Under these conditions, an attempt to relate an independent variable to the Manitoba Weather Severity Index would produce exactly the same degree of association as with snow depth, and the formation of an additive index would serve no purpose. Although problems with the data do not allow evaluation of the relationship between chillometer and snow depth, the strong relationship between pentrometer and snow depth suggests that combination of these 2 variables in an index is of extremely limited or no value in Manitoba.

The Concept of an Index

An index, as examined in this study, represents an attempt to formulate potentially complex relationships into a value which is simple to understand when making comparisons. A serious drawback to this procedure is that underlying relationships are masked and may be distorted. Also, the process of index formation leads to loss of information and incomplete use of data.

The formation of an index is understandable given the limited analytical tools available when Verme (1968) first used his Weather Severity Index; however, the need does not exist today. Green (1979)

stated:

> "It is better to use individual criteria or predictor variables in linear additive models and then let the relative magnitudes and signs of the coefficients in the linear additive functions be the basis for interpretation of criterion or predictor variable relationships."

Indices can be formulated within the framework of modern statistical techniques; however, such indices should be tested to ensure they provide information additional to the constituent variables. Additionally, the availability of interaction terms in modern techniques serves to enhance analysis of underlying relationships. A relationship between constituent variables, as exists for pentrometer and snow depth in Manitoba (this study, Soprovich and Hristienko 1989), can still create problems of analysis when modern statistical techniques are used.

ACCURACY OF HARVEST STATISTICS

As an indicator of the age and sex composition of the harvest from Game Hunting Areas 27 and 28, the bag check data were likely biased. Some unknown, but likely small, portion of the sample originated from outside these G.H.A.s (B. Pelechaty, Man. Dept. Nat. Resour., pers. commun.) and a bias would result if the composition of the harvest differed. A bias would also result if the harvest composition varied temporally, as found for unit B, and sampling was not consistent over the hunting season. This potential bias was the basis upon which data from 1984 and 1985 were deleted.

As the majority of bag check data came from hunters who lived outside the Game Hunting Areas (B. Pelechaty, Man. Dept. Nat. Resour., pers. commun.), it is likely that non-resident harvest was sampled disproportionately. If this did occur, and the harvest composition differed for resident and non-resident hunters, a bias would result. The harvest composition did not differ between resident and non-resident hunters from G.H.A.s 27 and 28 when questionnaire data from 1985 was examined. On this basis, it cannot be concluded that a bias towards sampling non-resident hunters in the bag check would result in biased harvest data; however, it is quite possible that differences might have been apparent with larger samples. For example, it was not possible to detect a difference in harvest composition between seasons for G.H.A.s 27

and 28 despite its existence for unit B, a larger area which encompassed these G.H.A.s and for which a large sample was available.

The assumption of a true difference in harvest composition between groups was used to assess the potential impact of a sampling bias. Despite maximization of such a bias through use of non-resident data to represent bag check data, the analysis suggested that the bias would have had minimal influence on harvest statistics. The influence was small because resident hunters are relatively few in number (at least, in the questionnaire data), thereby having limited effect on statistics. The analysis assumed that other forms of bias (eg., "brag" bias) and return rates were the same for both groups of hunters; however, return rates may differ, as found for rural versus resident of Winnipeg moose (Alces alces) hunters (Soprovich 1989).

Although likely somewhat biased, the bag check probably provided the most accurate estimate of the harvest age and sex composition from G.H.A.s 27 and 28. The data were collected by trained individuals, hence it should be free from errors which result when a hunter unable to determine the age and/or sex of his kill inaccurately completes a questionnaire. Additionally, this data is not subject to mechanical errors (eg., checking the wrong box) or "brag" bias (eg., hunters who kill antlerless deer sometimes report an adult male) which lead to inaccurate estimates with the questionnaire method (MacDonald and Dillman 1968). Although a sampling bias towards non-resident hunters likely occurs in the bag check, it would appear to have a relatively minor impact. MacDonald and Dillman (1968) and McPhillips et al. (1985) found that respondents were more successful than non-respondents when deer harvest information was gathered via the questionnaire method. As this likely occurs for deer in Manitoba, as documented for moose (Soprovich 1989), it is also likely the harvest composition of the relatively successful respondent group differs from that of the non-respondent group thereby causing biased estimates.

Estimates of the contribution of males to the adult harvest differed between bag check and questionnaire data, the magnitude of which was substantial for 1983. This result is consistent with MacDonald and Dillman (1968) who found the questionnaire method to provide an estimate of 41.7% males in the adult harvest when the known proportion was 35.4% (calculations from data in Table 2, MacDonald and Dillman 1968; reported

performance of unknown kill not included), a difference attributed to "prestige" ("brag") bias. Although a sampling bias towards non-residents in the bag check data may have had some impact, the high estimates for the Manitoba questionnaire data most likely resulted from non-response and response ("brag", etc.) bias for this method.

As occurred with the adult harvest, the contribution of fawns to the fawn plus adult female harvest differed by data source. Fawns were estimated to comprise less of the harvest when questionnaire data were used, a result consistent with MacDonald and Dillman (1968) who found the questionnaire method to provide an estimate of 22.5% when the known proportion was 27.5% fawns in the fawn plus adult female harvest (calculations from data in Table 2, MacDonald and Dillman 1968; reported performance of unknown kill not included). A biased sampling frame provides an explanation for the high estimates from the bag check data; however, the magnitude of the observed differences far exceeds the impact of such a potential bias. It is likely the questionnaire method underestimates the true proportion of fawns in the fawn and adult female harvest, perhaps due to "prestige" or non-response bias.

For the proportion of males in the fawn harvest, MacDonald and Dillman (1968) found the questionnaire method to provide an estimate of 58.5% when the known proportion was 52.6% (calculations from data in Table 2, MacDonald and Dillman 1968; reported performance of unknown kill not included). As males comprised only 8 of 29 (28%) fawns from field checks in G.H.A.s 27 and 28 during 1985 (B. Pelechaty, Man. Dept. Nat. Resour., unpubl. data), it is almost certain that the questionnaire overestimates this statistic (males averaged 69.3% of the fawn harvest from questionnaire data). The response bias documented by MacDonald and Dillman (1968) was most likely responsible for this bias, with an additional influence due to non-response.

For the contribution of males to the adult harvest, the lack of a relationship and extremely weak association between data sources were unexpected. If the bag check data provided a reasonable indicator of trend, this lack of relationship suggests that estimates provided by the questionnaire method are not reliable as a trend indicator, the primary purpose for which such data should be collected. As the accuracy of the bag check data is unknown, it is not possible to unequivocally state that

the questionnaire method provides unsound measures of this statistic; however, its utility as a trend indicator is subject to considerable question. Although no relationship was apparent, the high degree of association between data sources, given the small sample, suggests that questionnaire data are suitable to indicate trend for the proportion of fawns in the fawn and adult female harvest. To verify this possibility, more data are required.

Response bias in the questionnaire method of data collection results in over-reporting of adult males and under-reporting of fawns in the harvest (MacDonald and Dillman 1968). For this reason, past questionnaires from Michigan have not included questions on the age and sex of a kill (Ryel 1960 in Hawn and Ryel 1969). Comparison of questionnaire and bag check data in this study indicates that similar problems exist with questionnaire data from Manitoba.

Almost certainly, the questionnaire method overestimates the proportion of adult males and underestimates the proportion of fawns in the Manitoba harvest. If estimates are biased to the extent suggested by comparison to bag check data, such estimates would indicate that harvest of deer by sport hunting is having a far lesser impact upon the recruiting component of the deer population than really occurs. It is apparent that the role of sport hunting as a factor potentially limiting deer populations (eg., growth, recovery) is likely underestimated, and definitely understated, relative to the composition of the harvest. This underestimation is undoubtedly compensated somewhat by a non-response bias; however, this may serve only to make the management process more complex.

HARVEST STATISTICS AND WINTER SEVERITY

Yearling and adult females have greater fat reserves than yearling and adult males throughout the winter in South Carolina (Johns et al. 1984). In particular, the kidney fat index (Riney method) of adult and yearling males is very low relative to adult and yearling females during and after the rut (November and December). The consequence of this difference in condition, along with other aspects of sexual dimorphism (eg., dispersal by males), is that males are more vulnerable to predation (Nelson and Mech 1986, a number of authorities cited by Nelson and Mech 1986), and likely malnourishment than females.

Fawns have higher metabolic rates than older deer (Parker and Robbins 1984), although these high rates may be somewhat artificial due to low body fat reserves. As the cost of locomotion is related to snow depth (Fancy and White 1985), relatively small fawns might be stressed before older deer, although a bioenergetic model for the interactions between mule deer and their environment (Hobbs 1989) suggests that snow depth would have a relatively minor influence on expenditure, and that costs per $kg^{0.75}$ would be less for fawns. In the absence of data, Hobbs (1989) approximated the positive influence of utilizing the track of another deer, with fawns gaining more benefit than does (due, perhaps, to following in their dams track). Of particular importance, Hobbs' model indicated that excessive snow led to mortality of deer primarily through its influence on food quality. These factors, and the low body fat reserves of fawns as they enter the winter (Johns et al. 1984), are likely most responsible for fawns generally representing the majority of animals which starve to death (Sauer and Severinghaus 1983, D. W. Soprovich, Man. Dept. Nat. Resour., unpubl. data) and the high mortality rate of fawns over the winter (Sauer and Severinghaus 1983, Nelson and Mech 1986). Sauer and Severinghaus (1983) found recruitment into the yearling age class to relate directly to winter severity.

The greater mortality rate of males and fawns during the winter should generally have the following impact upon adult male/adult ratios (adult defined as yearling or older in this context). A mild winter should result in good survival and recruitment of fawns to the adult male component of the population. Combined with good survival of adult males, the adult male/adult ratio should generally remain stable or increase. Conversely, a severe winter which leads to poor recruitment plus significant adult mortality would be expected to depress the adult male/adult ratio.

Verme (1977) estimated birth weight at parturition for fetuses from does killed during April and May and found the estimated birth weight to be inversely related to weather severity (partial WSI of first and fifth months). Analysis of Verme's data indicates that estimated birth weight was also related to total WSI ($F = 12.98$, $df = 1,6$, $P < 0.025$). As survival of fawns is related to birth weight (Verme 1963), Verme (1977) suggested that natal losses would also relate to winter weather severity.

Verme (1977) also found a relationship between fawn/doe harvest ratios and estimated natal losses which suggests the existence of a relationship between recruitment and winter severity. For the Delta Marsh, Kucera (1976) found that snow cover, rather than wind chill, impacted net productivity through its influence on access to forage. As suggested by Hobbs (1989), the impact of the snow cover was likely on the quality of available forage, although amount can be negatively impacted (Moen and Evans 1971). These data suggest that recruitment in Manitoba, as measured from harvest statistics (fawn/fawn and adult female), would be influenced by weather severity.

Contrary to expectations, relationships were not apparent between the adult male/adult harvest ratio and the measures of weather severity in Manitoba, with slopes of the linear trends opposite to predicted and indicative of an increasing ratio with more severe winter weather. The measure of annual recruitment declined with increasing weather severity measures, as expected, but none of the relationships were statistically significant, perhaps due to the small sample. A statistically significant relationship between the questionnaire-generated measure of annual recruitment and chillometer exhibited no trend with the addition of 1 datum, an illustration of the inherent risk in making inferences from small samples. Additionally, as the chillometer did not accurately model thermal stress at Virden (D. W. Soprovich, Man. Dept. Nat. Resour., unpubl. data), this "significant" relationship might be expected to be spurious.

Bag check harvest statistics were not related to the WSI (Manitoba model), perhaps due to distortion of the Verme model through measurement of snow depth and pentrometer in metric units. Similarly, no relationship was found between questionnaire-generated harvest statistics and the Verme WSI, which suggests that other factors may have influenced harvest (eg., hunter selectivity, initial composition of population). For the winters examined, pentrometer varied from 96-422 cm•weeks, snow depth from 108-426 cm•weeks, chillometer from 113-156 kW•hours, and WSI (Manitoba model) from 320-1003. Although severe with respect to the chillometer (i.e., for 6 winters examined by Verme and Ozoga (1971), the average maximum cumulative chillometer datum was 85.1 kW•hours for a 5 month winter period), these winters were mild relative to snow depth (eg., the most severe winter had a mean weekly depth of only 22.4 cm between 3 December and 7 April), and

environmental variability may have been inadequate to adversely impact harvest ratios.

An indicator of recruitment would be most sensitive to environmental variation because substantial post-natal fawn mortality will occur before adult females die (Verme 1962). Verme (1977) reported fawn/fawn plus adult doe ratios between 0.390 and 0.552, the higher ratio much greater than reported in this study and due, perhaps, to inclusion of yearling deer (1.5 years) in the Manitoba estimates. Additionally, inclusion of yearlings in the Manitoba sample may be somewhat responsible for lack of variability in this statistic. Harvest ratios may also have been impacted by differing annual vulnerability of adult males to hunting (due to variable snow conditions and/or timing of the rut), variation in the condition of deer at the beginning and throughout the hunting season, and other factors. To adequately assess the influence of the winter environment on these harvest statistics, collection of further data is required.

FAILURE OF MODEL DEVELOPMENT

Ransom (1964) stated "The extreme importance of weather in the environmental resistance acting against deer in Manitoba is sufficient to invalidate the application of some deer management principles derived in areas where total food supply is the chief limiting factor." and "It is concluded that the efficient management of deer in Manitoba can only be based upon research carried out under Manitoba environmental conditions.". Key thoughts contained in these statements are the concept of uniqueness of the Manitoba environment and the requirement for research, due directly to the different conditions impacting white-tailed deer in Manitoba. Today, in 1990, these thoughts are no less important or real, as evidenced by some of the data examined in this study.

Firstly, an attempt was made to use a model (Verme 1968) developed for an environment and habitat considerably different from that of Manitoba. Secondly, in Manitoba, standards of data collection necessary for application of the Verme WSI were not adhered to. In particular, this was apparent with site selection of chillometers, but also occurred with use of the pentrometer. Thirdly, calculation of the WSI with snow depth and pentrometer in metric equivalents completely invalidated use of the

model. Fourthly, data were collected for 6 years despite obvious problems with the Brandon chillometer data by the second year of collection. These problems include not only those which Ransom (1964) warned of more than 25 years ago, but also fundamental weaknesses in the collection of data for any purpose.

There are almost certainly diverse reasons for failure of this program of data collection; however, foremost may have been a weakness in organizational structure. The objective of collecting chillometer, snow depth, and pentrometer data should have been to validate Verme's model, with the proviso to build a new model if, as expected (Ransom 1964), Verme's model was not correct for Manitoba. Modeling teams generally include managers and researchers whose interests are often very different (Bunnell 1989). Managers are typically interested in models for their predictive capabilities (e.g., as in the number of deer which die as related to winter conditions) while researchers are often most interested in furthering understanding. It is speculated that the problems of data collection, and subsequent inability to use data for its intended purpose, were due, in part, to limited or no involvement of a researcher in the attempt to meet the objectives of the program. Managers are best qualified to determine their needs; however, researchers are best qualified to correctly build models (Bunnell 1989). It is the researcher, trained in the scientific method, comfortable with the collection, analysis, and use of data, and attentive to detail, who will best recognize if data are being collected properly and objectives can and are being met. Finally, by not conceptualizing the management process as an experiment (McNab 1983), exceptional opportunities of validation for accuracy and precision (management goal) and corroboration for understanding (research goal) are not recognized and therefore, lost.

RECOMMENDATIONS

1. To ensure, as much as possible, that funds and time are not wasted, all new programs of data collection must initially, and during early collection of data (until the program is operational as a decision-making tool), include a researcher familiar with statistics, experimental design, and the scientific method to assist program

evaluation. A required analysis plan would specify how data would lead to decision, necessary statistical tests, precision, and sampling intensity.

2. The accuracy of questionnaire-generated estimates of harvest composition must be evaluated if such data are to be used for management of white-tailed deer.
3. Although more data are required to establish veracity, the questionnaire-generated estimate of recruitment appears adequate as a trend indicator. The questionnaire-generated estimate of composition of the adult harvest should not be used by wildlife managers because it is apparently both inaccurate and unable to indicate trend. Due to inaccuracy, these statistics must be used with extreme caution (eg., their use in a simple add/subtract ungulate model) in attempts to determine the impact of sport harvest on white-tailed deer population dynamics.
4. To manage the white-tailed deer resource effectively near the northern limit of its range, the relationship between white-tailed deer and winter weather must be determined for Manitoba environmental conditions; however, this requires research designed specifically for this purpose, not the fortuitous collection of data. In this context, the pentrometer and chillometer cannot presently be used to assess weather severity for white-tailed deer in southwestern Manitoba. Snow depth is almost certainly the primary winter environmental variable leading to substantial mortality and poor recruitment, and knowledge of these relationships is of particular importance due to their direct impact on hunting opportunity and winter deer feeding programs.
5. Assess techniques developed elsewhere for their applicability under Manitoba environmental conditions and do not apply relationships developed elsewhere until verified for Manitoba.
6. Do not distort, through metrification or any other means, techniques developed elsewhere. If attempting to evaluate a technique developed elsewhere, collect the data in exactly the same manner detailed.
7. Do not formulate indices except when they will be tested for improvement of biological relationships.

LITERATURE CITED

Baker, R.H. 1984. Origin, classification and distribution. Pages 1-18 in L.K. Halls, ed. White-tailed deer ecology and management. Stackpole Books, Harrisburg, Pennsylvania. 870 pp.

Bunnell, F.L. 1989. Alchemy and uncertainty: what good are models? U.S. For. Serv., Pacific Northwest Res. Stn., Portland, Oregon. 27 pp.

Chranowski, D.J. 1982. Winter weather and white-tailed deer in the Southwestern Region - 1982. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 82-24. 33 pp.

Chranowski, D.J. 1983. Winter weather and white-tailed deer in the Southwestern Region - 1983. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 83-18. 34 pp.

Chranowski, D.J. 1984. Winter weather and white-tailed deer in the Southwestern Region - 1984. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 84-13. 36 pp.

Chranowski, D.J. 1985. Winter weather and white-tailed deer in the Southwestern Region - 1985. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 85-14. 47 pp.

Fancy, S.G., and R.G. White. 1985. Incremental cost of activity. Pages 143-160 in R.J. Hudson and R.G. White, eds. Bioenergetics of wild herbivores. CRC Press, Inc., Boca Raton, Florida. 314 pp.

Gates, C.C., and R.J. Hudson. 1981. Habitat selection by wapiti in a boreal forest enclosure. Naturaliste Can. 108:153-166.

Goulden, H.D. 1984. White-tailed deer management and use in Manitoba. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 84-9. 19 pp.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, Inc., New York, New York. 257 pp.

Hawn, L.J., and L.A. Ryel. 1969. Michigan deer harvest estimates: sample surveys versus a complete count. J. Wildl. Manage. 33:871-880.

Hobbs, N.T. 1989. Linking energy balance to survival in mule deer: development and test of a simulation model. Wildl. Monogr. No. 101. 39 pp.

Hummelt, C.A. 1986. 1985/86 big game hunter survey. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 86-29. 39 pp.

Johns, P.E., M.H. Smith, and R.K. Chesser. 1984. Annual cycles of the kidney fat index in a southeastern white-tailed deer herd. J. Wildl. Manage. 48:969-973.

Karns, P.D. 1980. Winter - the grim reaper. Pages 47-53 in R.L. Hines and S. Nehls, eds. Proc. symposium on white-tailed deer population management in the north central states. North Cent. Sect., The Wildl. Soc., Urbana, Illinois. 116 pp.

Kucera, E. 1976. Effects of winter conditions on the white-tailed deer of Delta Marsh, Manitoba. Can. J. Zool. 54:1307-1313.

MacDonald, D., and E.G. Dillman. 1968. Techniques for estimating non-statistical bias in big game harvest surveys. J. Wildl. Manage. 32:119-129.

McNab, J. 1983. Wildlife management as scientific experimentation. Wildl. Soc. Bull. 11:397-401.

McPhillips, K.B., R.L. Linder, and W.A. Wentz. 1985. Nonreporting, success, and wounding by South Dakota deer bowhunters - 1981. Wildl. Soc. Bull. 13:395-398.

Milliken, I.J. 1978. Winter weather and white-tailed deer in the Brandon sub-region - 1978. Manitoba Dept. Renew. Resour. Trans. Serv. Manuscr. Rep. No. 78-59. 33 pp.

Milliken, I.J. 1981. Winter weather and white-tailed deer in the Southwestern Region - 1980 and 1981. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 81-18. 45 pp.

Moen, A.N. 1968. Energy exchange of white-tailed deer, western Minnesota. Ecology. 49:676-682.

Moen, A.N. 1973. Wildlife ecology. W.H. Freeman and Company, San Francisco, California. 458 pp.

Moen, A.N., and K.E. Evans. 1971. The distribution of energy in relation to snow cover in wildlife habitat. Pages 147-162 in A.O. Haugen, ed. Proc. snow and ice in relation to wildlife and recreation symposium. Iowa State University, Ames, Iowa. 280 pp.

Nelson, M.E., and L.D. Mech. 1986. Mortality of white-tailed deer in northeastern Minnesota. J. Wildl. Manage. 50:691-698.

Parker, K.L., and C.T. Robbins. 1984. Thermoregulation in mule deer and elk. Can. J. Zool. 62:1409-1422.

Pruitt, W.O. Jr. 1981. Application of the Varrio Snow Index to overwintering North American barren-ground caribou (Rangifer tarandus arcticus). Can. Field-Nat. 95:363-365.

Ransom, A.B. 1964. Reproductive biology of white-tailed deer in Manitoba. M.Sc. Thesis, Univ. Alberta, Edmonton. 75 pp.

Sauer, P.R., and C.W. Severinghaus. 1983. Relationship of degree and composition of winter mortality of deer, as indicated by strip surveys, to severity of the winter. N. Y. Fish Game J. 30:173-181.

Soprovich, D.W. 1989. An assessment of the accuracy of the Manitoba general moose hunter questionnaire survey. Manitoba Dept. Nat. Resour. Tech. Rep. No. 89-02. 130 pp.

Soprovich, D.W., and H. Hristienko. 1989. Assessment of the Verme weather severity index as applied in Manitoba. Manitoba Dept. Nat. Resour. Tech. Rep. No. 89-01. 50 pp.

Telfer, E.S., and J.P. Kelsall. 1979. Studies of the morphological parameters affecting ungulate locomotion in snow. Can. J. Zool. 57:2153-2159.

Vanderpont, C.A. 1981. 1980/81 big game hunter survey. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 81-28. 25 pp.

Vanderpont, C.A. 1982. 1981/82 big game hunter survey. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 82-29. 29 pp.

Vanderpont, C.A. 1983. 1982/83 big game hunter survey. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 83-5. 27 pp.

Vanderpont, C.A. 1984. 1983/84 big game hunter survey. Manitoba Dept. Nat. Resour. Manuscr. Rep. No. 84-21. 22 pp.

Verme, L.J. 1962. Mortality of white-tailed deer fawns in relation to nutrition. Proc. Deer Disease Symp. 1:15-32.

Verme, L.J. 1963. Effect of nutrition on growth of white-tailed deer fawns. Trans. N. Am. Wildl. Conf. 28:431-443.

Verme, L.J. 1968. An index of winter weather severity for northern deer. J. Wildl. Manage. 32:566-574.

Verme, L.J. 1977. Assessment of natal mortality in Upper Michigan deer. J. Wildl. Manage. 41:700-708.

Verme, L.J., and J.J. Ozoga. 1971. Influence of winter weather on white-tailed deer in Upper Michigan. Pages 16-28 in A.O. Haugen, ed. Proc. snow and ice in relation to wildlife and recreation symposium. Iowa State University, Ames, Iowa. 280 pp.